Enzyme Sugar-Ethanol Platform

Web site for Gate 3 Review Presentations

www.ott.doe.gov/biofuels/enzyme_sugar_platform.html

NREL, Golden, Colorado

January 30-31, 2002

National Renewable Energy Laboratory

Operated for the U.S. Department of Energy by Midwest Research Institute • Battelle • Bechtel

Enzyme Sugar-Ethanol Platform Project
Gate 3 Review Meeting
January 30th & 31st, 2002
Agenda

Objective: Demonstrate Completion of Stage 2 (Detailed Investigation), and Outline and Refine Plans for Stage 3 (Process Development)

Wednesday, January 30th

8:00 Registration

8:30 Gate Review Expectations and Meeting Format

9:00 Project Overview

9:30 Ethanol Market Assessment

10:00 Break

10:15 The Technology and Economic Assessment of it

11:30 Life-Cycle Analysis of Ethanol From Stover

11:45 Questions

12:00 Buffet Lunch

12:30 Feedstock Collection and Sustainability

1:00 Pretreatment Options and Selection

2:00 Break

2:10 Enzyme Development Progress

2:30 Fermentation Organism Screening

3:00 Questions

3:15 Break

3:30 Business Plan
Overall Plan
Colloquies Results
Letter of Intent for Engineering Demonstration Plant

4:15 Stage 3 Overview

4:30 Questions

5:30 Adjourn for the Day

Thursday, January 31st

8:30 Recap Previous Day's Comments and Solicit and Additional Comments

9:15 Stage 3 Plan (Incorporating Previous Day's Feedback)

10:15 Break

10:30 Open Discussion Led by Review Panel to Critique/Improve Stage 3 Plan

11:30 Adjourn

Optional – NREL Bioenergy Facilities Tour (RSVP necessary to billie_christen@nrel.gov)

1:30 Tour of the Alternative Fuels User Facility Laboratories and Process Development Unit Pilot Plant (90 Minutes)

3:00 Depart NREL

National Renewable Energy Laboratory

Enzyme Sugar Platform Project Gate 3 Review

Introduction and Objectives

Robert Wooley

January 30, 2002

Genencor International

USDA

novozymes

Outline

- Biofuels Program Overview
- Biofuels Stage Gate Process
- Meeting Objectives
- Meeting Format and Process

Program Overview

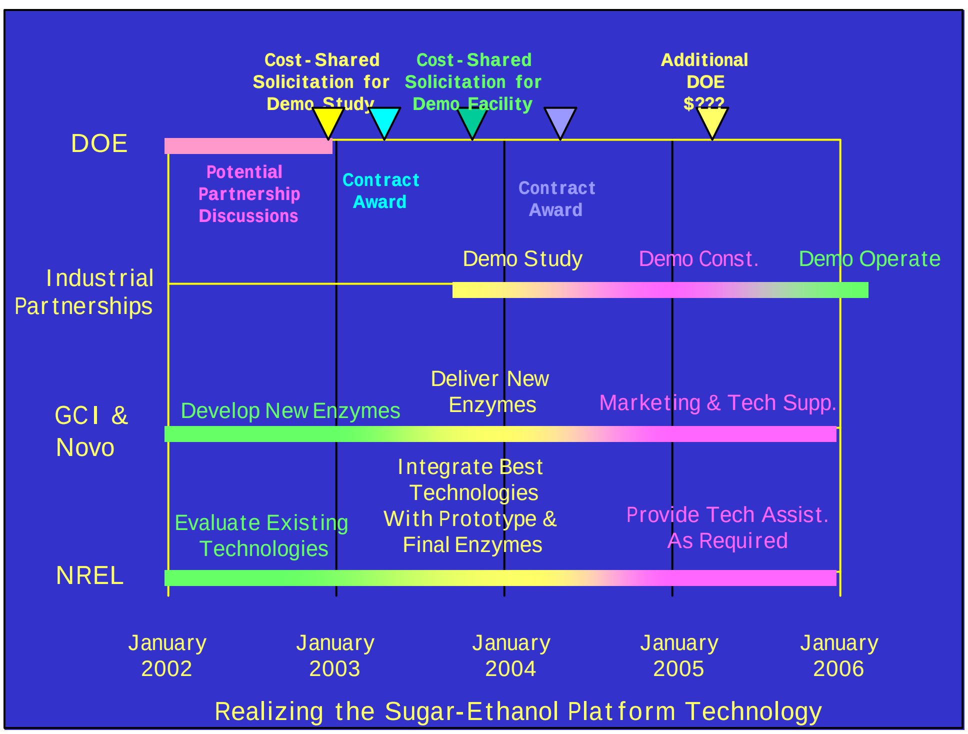
- Mission – Support the commercialization of Biofuels technology
  - Bioethanol
  - Renewable Diesel
- The Government will not commercialize technology directly. We will:
  - Map out routes and carry out early stages of high risk R&D to develop new technology
  - Enable industry to undertake final development stages

Specific DOE Program Targets

- Commercial production of ethanol from agricultural residues, such as corn stover, by 2010. Target cost: $1.07/gallon.
- Commercial production of ethanol competitive with gasoline on BTU basis, by 2025. Target cost: $0.60/gallon.

Big Picture: Multiyear Tech. Plan

- Near Term Pioneer Plants (1st Generation)
  - Low or negative cost feedstocks
  - Chemical hydrolysis technologies
  - Integration with existing plants (corn mills)
  - Advantageous situation and/or public policies
- Enzyme/Sugar Platform (2nd Generation)
  - Available feedstocks - eg. Corn stover
  - Enzyme hydrolysis, Chemical Pretreatment
- 3rd Generation Biorefinery
  - Advanced conversion and biotechnologies
  - Energy Crops



Stage Gate = A Management System

- Originally proposed by R. Cooper as a model for **product development** projects to reduce costs and time to market
- Adapted and extended to basic research by process R&D organizations for **process technology development**
  - Exxon, Rohm and Haas, Eastman Chemical
- Modified by USDOE Biofuels Program for early stage, high risk **Government-funded technology R&D** to insure alignment with industry needs for late stage development and commercialization

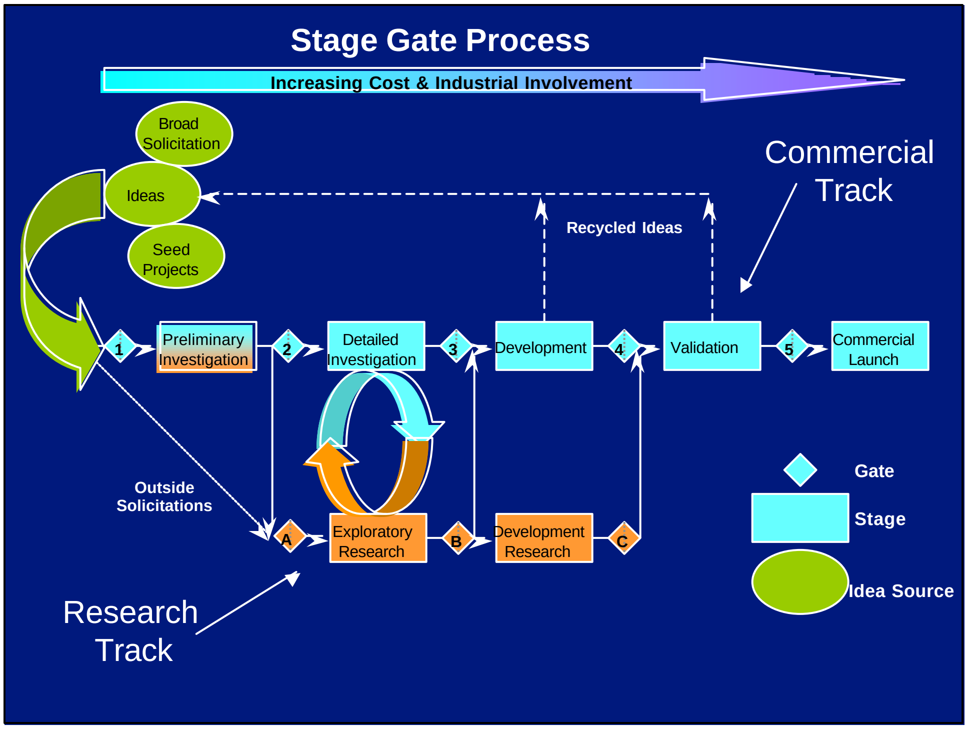
Goal for Stage Gate Process

- "Bring science and technology to commercial application sooner, at lower cost, and with improved probability of success."

Through:

- Strong Customer/Competition orientation
- Better homework up-front
- Quality of execution
- Sharper focus, better prioritization
- Fast-paced, parallel processing
- Multifunctional team approach

"Business Driven Science"



Major Categories in Each Stage

- Market Assessment
- Research Activities – *vast majority of $ spent here*
- Competitive Technology/Detailed Technical Assessment
- Financial Assessment

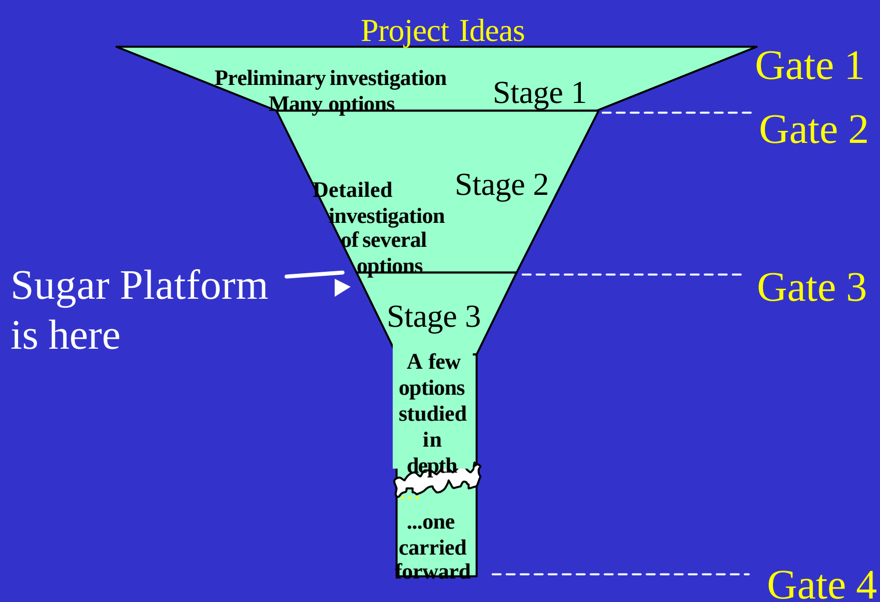
✍ **Result: Decisions and priorities regarding research are informed relative to market, competition, and economics.**

What Stage Gate Process Does

- Enables decisions on what projects belong in portfolio.
- Aligns R&D objectives with Program objectives.
- Provides high-level project definition including guidance on scope, quality, outputs, and integration.
- Reviews projects to evaluate progress and continuing fit in the Program portfolio.

✍ **It is the link between Strategic/Tactical Plans and R&D projects.**

Technology Selection Strategic Funnel



Expectations for Stages 2 and 3

- Stage 2 - Detailed Investigation
  - Emphasis on technical investigation and assessment
  - Critically investigate all aspects of background
  - Demonstrate key process feasibility
  - Develop a preliminary, plausible business plan
- Stage 3 – Development
  - Emphasis on technology integration and increased process knowledge including scale-up
  - Develop convincing data to resolve critical issues identified in Stage 2
  - Convert preliminary Stage 2 business plan into defined demonstration/commercialization plan

Meeting Objectives

1. Gate 3 (Between Stage 2 & 3) Review fo 3
   the Enzyme Sugar Platform Project
   1. Review Stage 2 accomplishments against plan and Gate 3 criteria
   2. Review general Stage 3 plan
   3. Gate Keepers make recommendations on next steps, including Stage 3 plan
2. Inform industry stakeholders of the Sugar Platform Project
   1. Looking for feedback and suggestions
   2. Provide background in anticipation of DOE Request for Letter of Interest (LOI).

Meeting Format And Process

- **Presentations**
  - Time for oral questions and clarifications
  - Process for written questions, comments, suggestions
- **Gate Keeper Review Panel and Role**
  - **Rod Fisher – Cargill**
  - **Scott Nichols – Dupont**
  - **Dale Monceaux – Katzen International**
  - **Mel Pearson – Kvaerner**
- **Audience Role**
- **Facilitator – Lynn Billman**

Today

- **Project Overview**
- Market Assessment
- Technical and Economic Analysis
- Life Cycle Analysis
- Feedstock
- Pretreatment
- Enzyme
- Fermentation Microorganism
- Business plan
- High-level Stage 3 plan

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Enzyme Sugar-Ethanol Platform

Project Overview

James D. McMillan

Gate 3 Review Meeting

NREL, Golden, Colorado

January 30-31, 2002

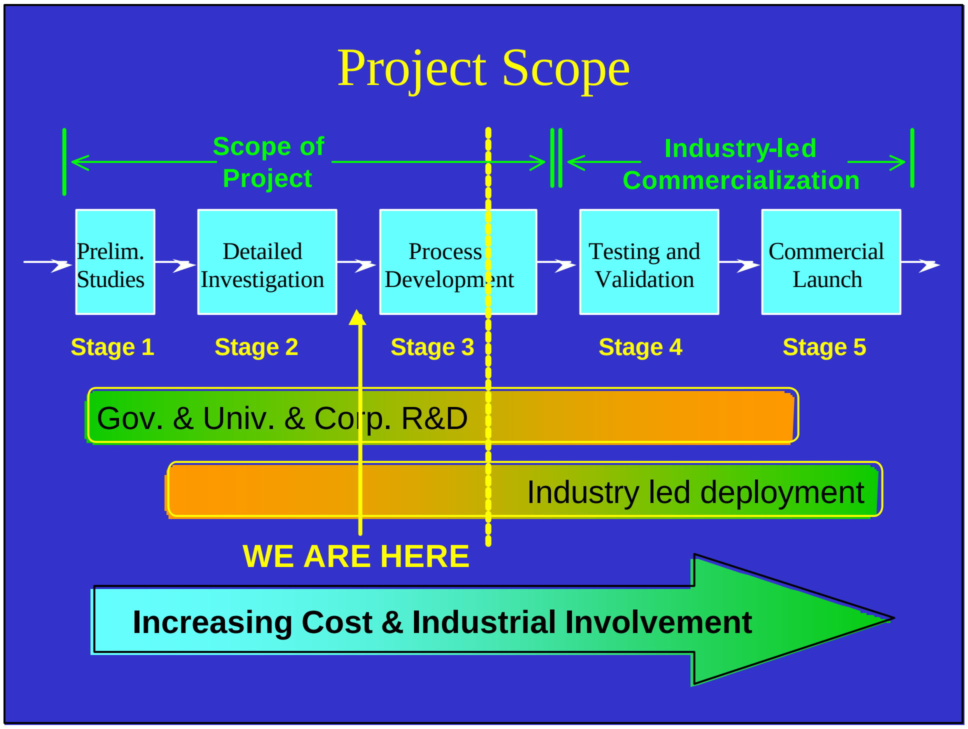
Project Overview Outline

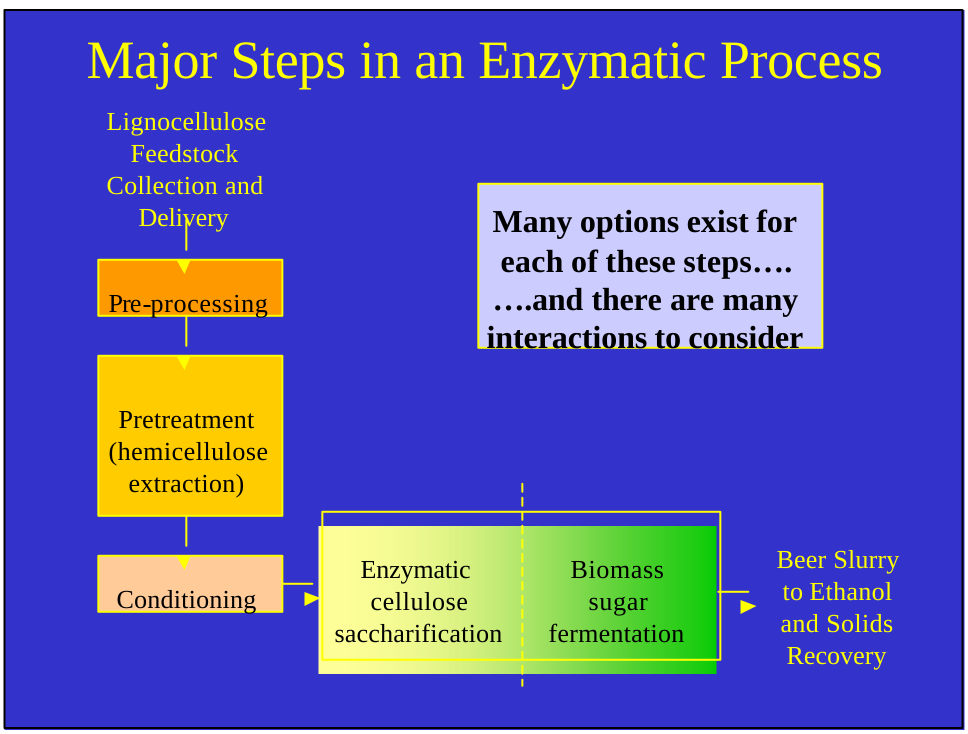
- **Objectives, Scope, and Strategic Fit**
- Approach
- Timeline
- Key Issues
- Outline of what you'll be seeing today

Project Goal

- **Objective**: Develop and demonstrate economical bioethanol technology based on ***enzymatic cellulose hydrolysis***

- **Feedstock Constraint**: Develop the technology for an abundant biomass resource that can support production of at least ***3 billion gallons*** of ethanol per year


Project Scope
Scope of Project
Industry-led Commercialization
Prelim. Studies
Detailed Investigation
Process Development
Testing and Validation
Commercial Launch
Stage 1
Stage 2
Stage 3
Stage 4
Stage 5
Gov. & Univ. & Corp. R&D
Industry led deployment
WE ARE HERE
Increasing Cost & Industrial Involvement

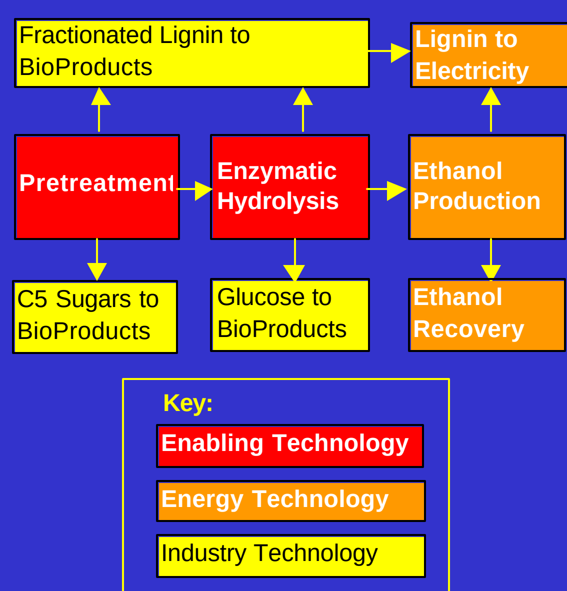

Major Steps in an Enzymatic Process
Lignocellulose Feedstock Collection and Delivery
Pre-processing
Pretreatment (hemicellulose extraction)
Conditioning
Enzymatic cellulose saccharification
Biomass sugar fermentation
Beer Slurry to Ethanol and Solids Recovery
Many options exist for each of these steps….
….and there are many interactions to consider

Strategic Fit

- This project plays a central role in the Ethanol Project's Multiyear Technical Plan
  - Largest and most complex commercialization project
  - Builds on other major program efforts
  - Enables core biorefinery technology
  - Demonstrates environmental "life cycle" benefits
- Success of niche pioneer plants based on acid hydrolysis technology will build a commercial experience base and reduce risk
- Success of enzyme developers will provide the key enabling technology

Strategic Fit: Enabling Biorefineries

- The project demonstrates enabling technology for a lignocellulose-based biorefinery
- The project focuses on the core steps needed to produce sugars, fractionated lignin, and ethanol
- Industry is focusing on the application of this technology to make new products



Project Overview Outline

- Objectives, Scope, and Strategic Fit
- **Approach**
- Timeline
- Key Issues
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Approach

- Corn stover selected as the ***model*** feedstock
  - Most abundant, concentrated domestic biomass resource
  - Potential to leverage off of the existing corn harvesting and ethanol production infrastructure (starch-based)
  - Conversion technology for corn stover should be readily adaptable to other lignocellulosic feedstocks
    - Core technology will be effective for other agricultural residues

Approach, cont’d

- Leverage ORNL and USDA efforts to develop a feedstock collection infrastructure
  - Determine how much corn stover can be removed
    - Critical to maintain soil quality/health
  - Study collection logistics and reduce costs
    - Critical to decreasing the cost of delivered feedstock

Approach, cont’d (2)

- Utilize low cost enzymes now being developed by the world’s leading industrial enzyme producers
  - Genencor International and Novozymes (through Novozymes Biotech) are developing inexpensive cellulases through cost-shared subcontracts from the USDOE.
  - Lower cost enzymes should become available in 2003-2004

Project Overview

- Objectives, Scope, and Strategic Fit
- Approach
- **Timeline**
- Key Issues
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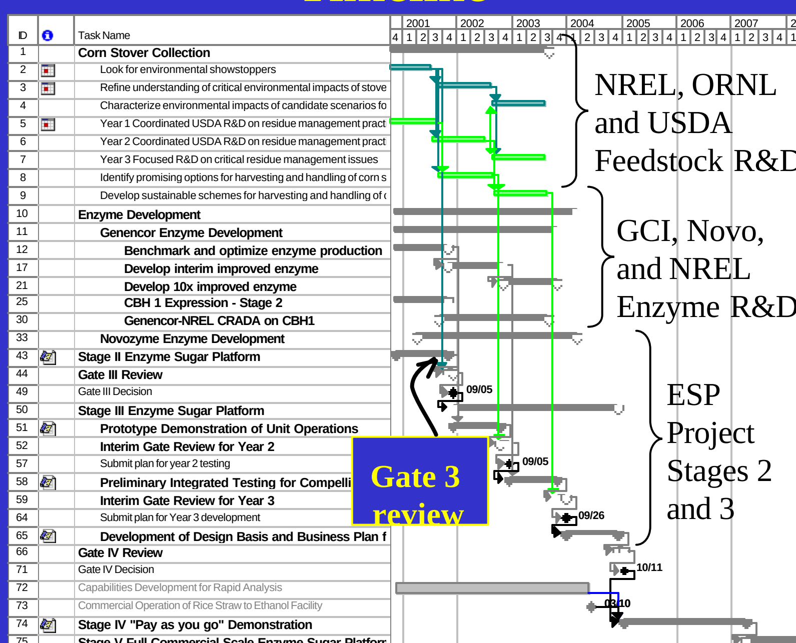
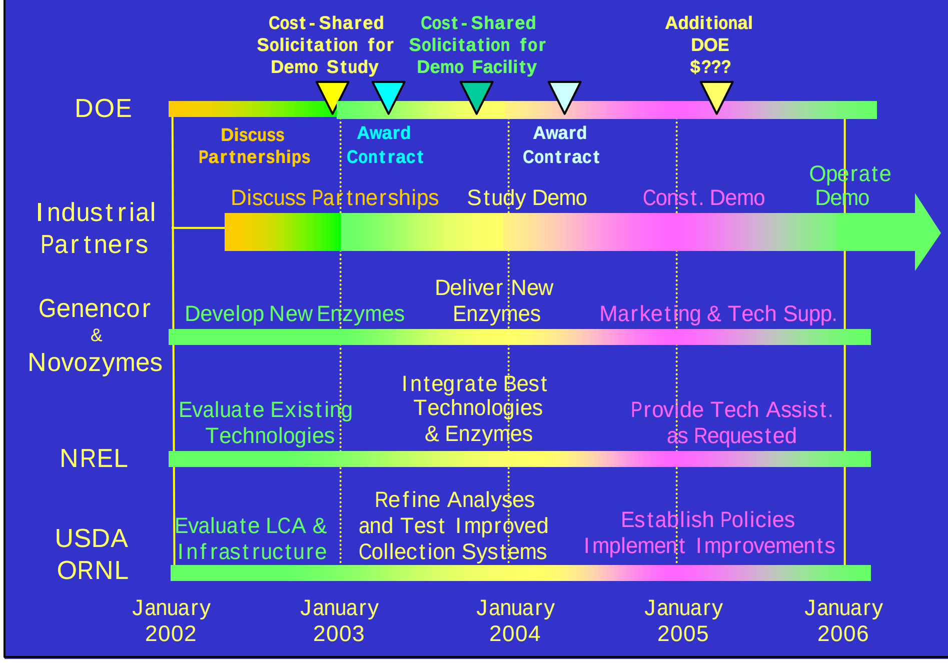
Timeline



Major Timeline Elements by Participant



Project Overview Outline

- Objectives, Scope, and Strategic Fit
- Approach
- Timeline
- **Key Issues**
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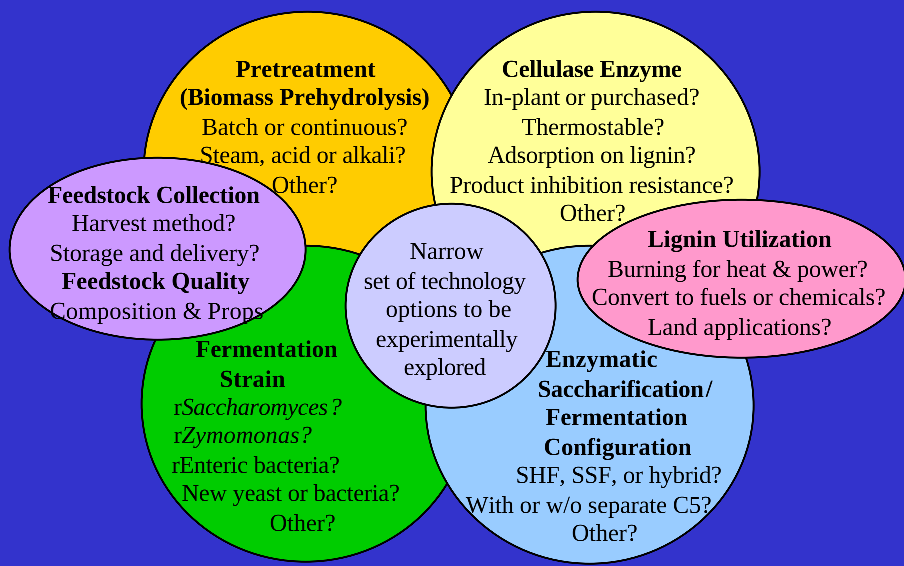
Many Process Development Options!



Key Issues (Gate 3 Criteria)

- Market opportunity
- Technical feasibility and risks
- Competitive advantage
- Legal and regulatory hurdles
- Critical success factors
- Showstoppers

What Does Success Look Like?

- Demonstrate robust integrated conversion process with compelling economics and a favorable outlook for commercialization.
  - Success represents industry leading subsequent development efforts, beginning with Stage 4 process testing and validation.

Critical Success Factors

1. Sufficient quantities of corn stover must be available at an acceptable cost.
   - Policies and infrastructure need to be developed for feedstock collection, storage, transportation and delivery.
2. Cost-effective cellulases must be available for process development and scale up (Stages 3-5).
3. The integrated process must be demonstrated to perform at levels required for attractive economics.

Feedback from Gate 2 Review

- Passed Gate 2 review 1/24/01
- Review panel charge:
  – Develop more economically compelling scenarios for pioneer plant commercialization
  – Involve pretreatment and fermentation strain technology developers in technology selection
- Stage 2 work has focused on this

Project Overview Outline

- Objectives, Scope, and Strategic Fit
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- Key Issues
- **What you'll be seeing today**

Order of Today's Presentations on Stage 2 Accomplishments

- Part I: Conceptual Analysis
  - Market Assessment
  - Technical and Economic Analysis
  - Life Cycle Analysis
- Part II: Process Element Investigation
  - Feedstock
  - Pretreatment
  - Enzyme
  - Microorganism
- Part III: Technology Deployment Plan
  - Business plan
  - High-level Stage 3 plan

Part I: Presentations

- ✍ Market Assessment – John Ashworth
- ✍ Technology & Economic Assessment – Andy Aden
- ✍ Life Cycle Assessment – John Sheehan

Today

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Market Assessment

John Ashworth

Operated for the U.S. Department of Energy by Midwest Research Institute • Battelle • Bechtel

Understanding the U.S. Fuel Ethanol Market

- Ethanol today is produced largely from corn
  - Wet mills –large facilities that produce a wide range of products besides ethanol (71% EtOH output in 2000)
  - Dry mills –tend to be smaller facilities making ethanol and distiller dried grain--DDG (29% EtOH output in 2000)
  - Most of new capacity added in 2001 –dry mills
  - Combined Federal and state tax credits range from $0.53 – 0.75 per gallon for major corn producing areas

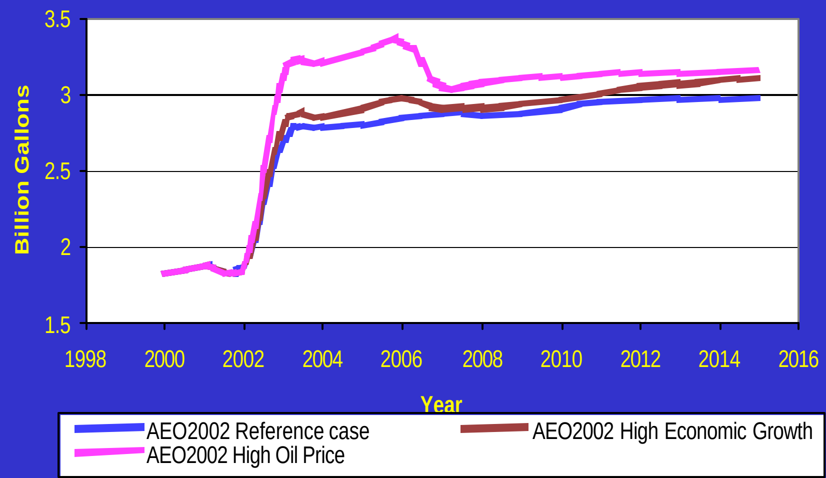
What can we say about the U.S. Ethanol Market 2000 – 2015?

- Rapid growing demand
- Increasing wholesale prices
- Large potential to take market share from other octane enhancers and oxygenates in the U.S. gasoline pool
- Potential for large, sudden increases in demand due to political mandates (MTBE phase-out, Renew. Fuels Standards, etc.)

An Expanding Near-term & Medium-Term Market

- The U.S. ethanol market is projected by U.S. DOE/EIA to grow rapidly in the near future, even in business as usual cases
- 50% rise in EtOH consumption in next five years is expected
- High economic growth or higher oil prices will accelerate EtOH usage above 50%
- Any additional MTBE phase-out will increase both demand and market prices

Projected U.S. EtOH Market Growth, 2000-2015



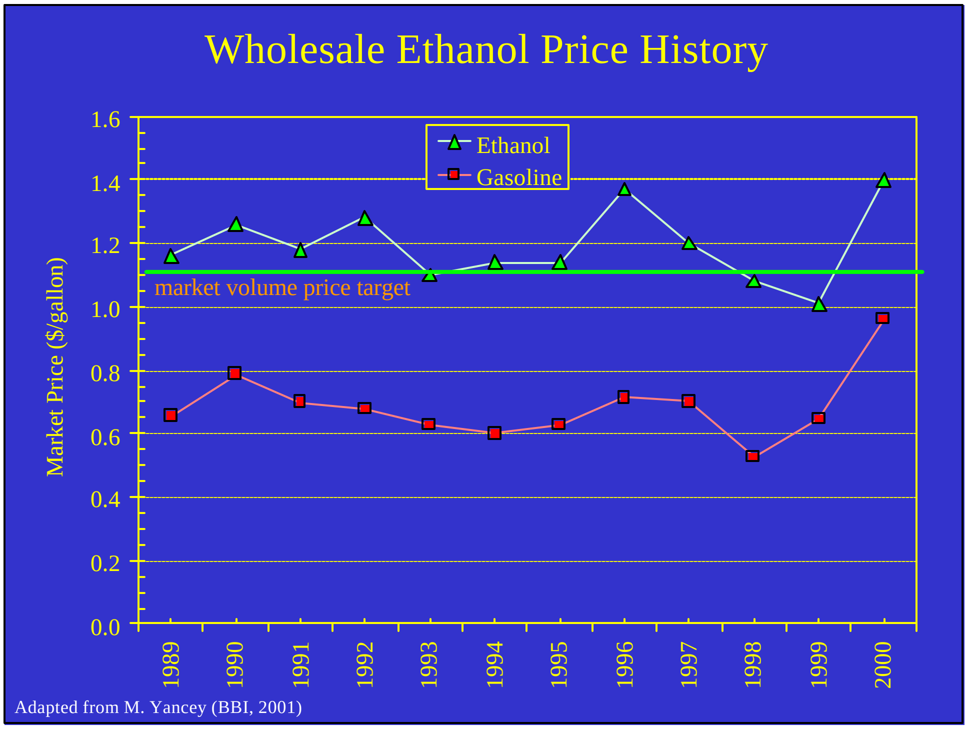
Uncertainties mostly favor greater rather than smaller EtOH usage

- Higher oil prices
- Higher economic growth
- Phaseout of MTBE for gasoline
- State mandates for EtOH blending to meet RFG and oxy-fuel requirements
- Federal Renewable Fuels Standard

Finding a conservative target price point for cellulosic ethanol

- Should be below historic price trends in order to capture market share from existing technology
- Should build in substantial profitability for early adopters of technology, to make up for risk and uncertainty

✍ $1.10/gallon provides that profitability



Double-checking Our Price Point

- Merrick using a conservative ethanol price of \$1.18-1.20/gal for plant feasibility economic analysis, which includes a marketing cost of \$0.03-0.05/gal.
- Pricing at a discount below this price less marketing costs provides financial incentive

✍ *Large uncertainties exist in market forecasts*

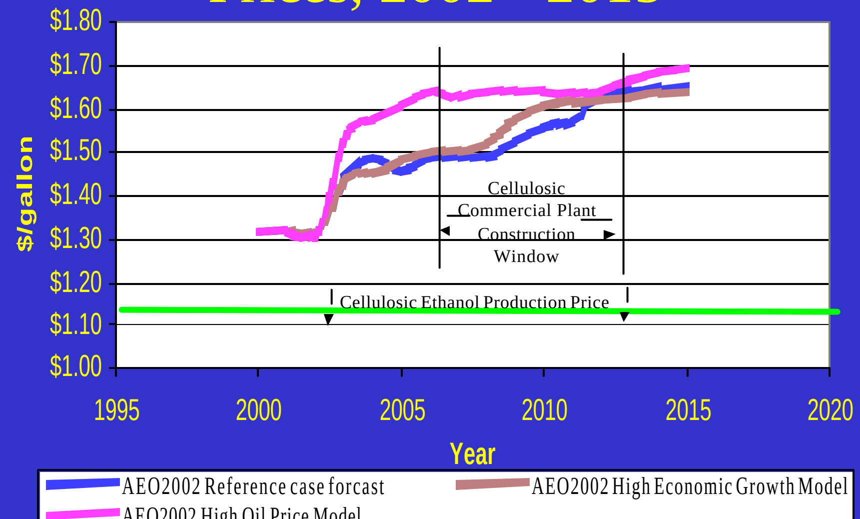
✍ *Extend market assessment in Stage 3 to better understand external showstoppers*

F. Ferraro (Merrick, 2001)

Market prices driven by rising demand and utility to blenders

- Gasoline blends use ethanol to add octane and oxygenate to RFG and oxygenated fuels
- Alternatives for octane are standard octane blending stock (alkylates, reformates, etc).
- Alternatives for oxygenate are ethers (MTBE, TAME, etc.)
- Market not expected to be in equilibrium for many years

Projected Wholesale Ethanol Prices, 2002 - 2015



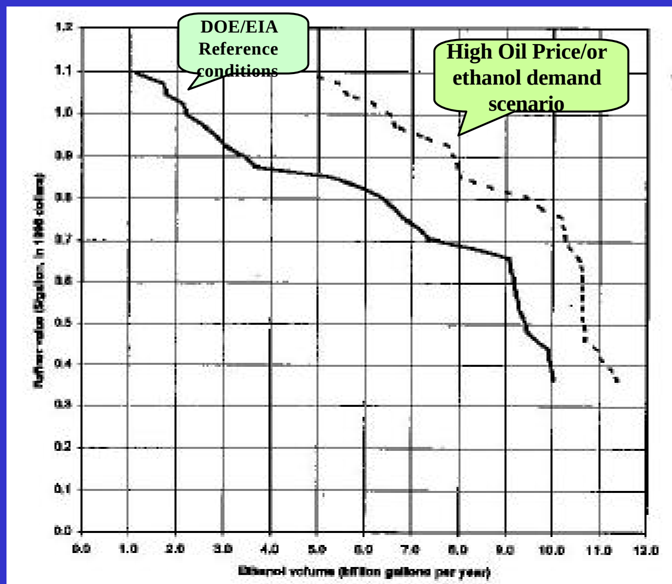
Looking at Future EtOH Blending Values vs. Wholesale Prices

- Market prices reflect supply vs. demand at point in time – system not necessarily balanced in period of rapid change
- Underlying value of EtOH is for adding octane vs. other blending stocks
- Value to refiner or blender changes with each incremental gallon of supply
- As supply increases, amount blender will pay for each additional unit decreases

Ethanol Value-Demand Curve

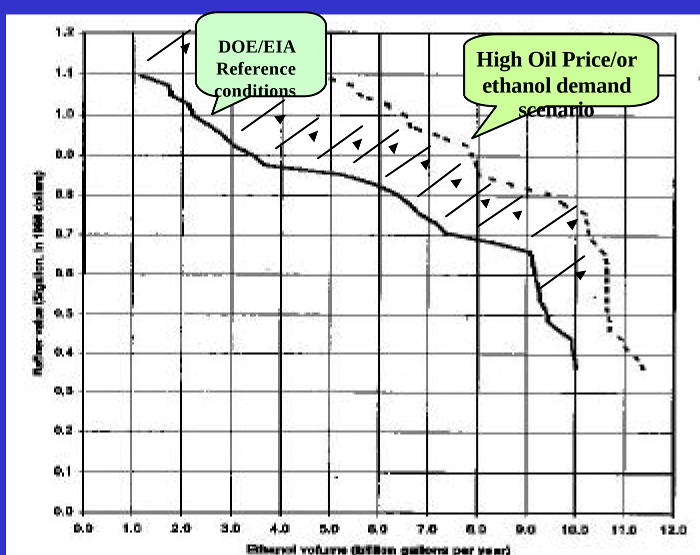
- Jerry Hadder's (ORNL) linear programming model for a generic oil refinery used to estimate ethanol value to blender as a function of supply.
- Blending value is normally below market price
- Results quantify how the value of ethanol decreases as more of it is blended
- This analysis conservative: does NOT include MTBE phase-out or RFS
- Does not include governmental subsidies

Refiner Ethanol Value Curve



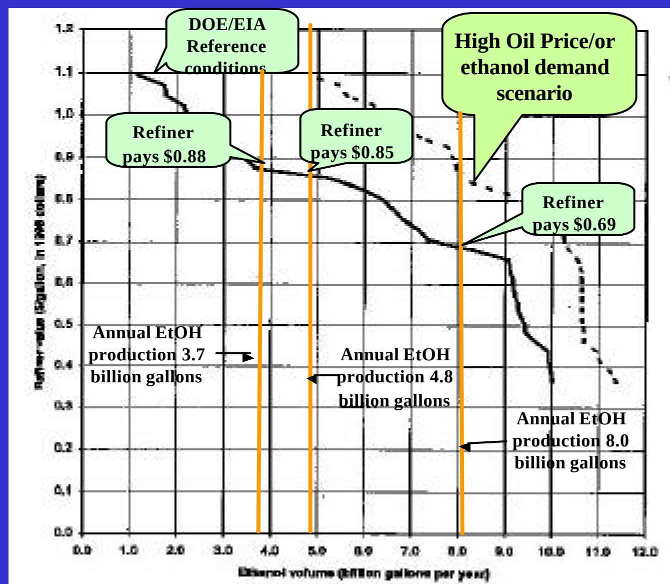
From G. Hadder
(ORNL, 1999)

Higher Gasoline Prices or Reduction in Other Blend Stock Supplies Moves Value Curve



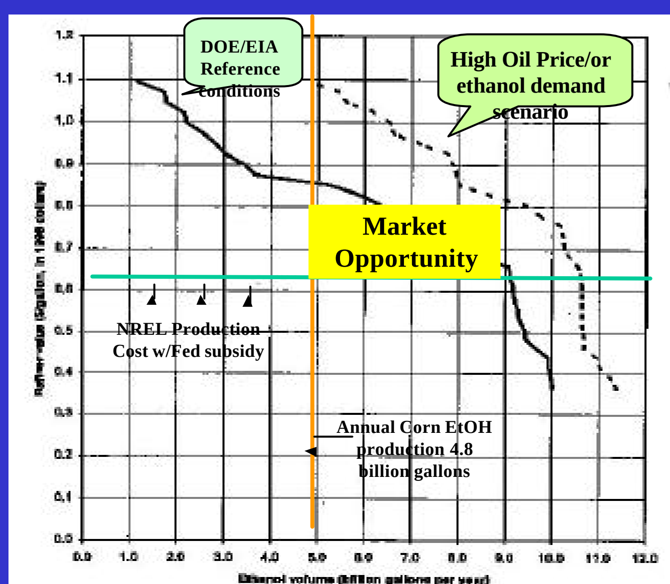
From G. Hadder
(ORNL, 1999)

Blender's Ethanol Values at different production volumes



From G. Hadder (ORNL, 1999)

Cellulosic Market Opportunity



From G. Hadder (ORNL, 1999)

Blender Value Curve Findings

- At $1.10 per gallon, blender will chose to use 1-5 billion gallons per year of ethanol as octane or oxygenate, depending on the future price of petroleum and GNP growth
- This volume estimate does **NOT** include the effect of federal or state EtOH production tax incentives
- If the federal tax incentive continues at $0.50 per gallon ethanol, gasoline blenders can afford to use 9 -10.5 billion gallons per year

Uncertainties in the Long-term EtOH Market Analysis

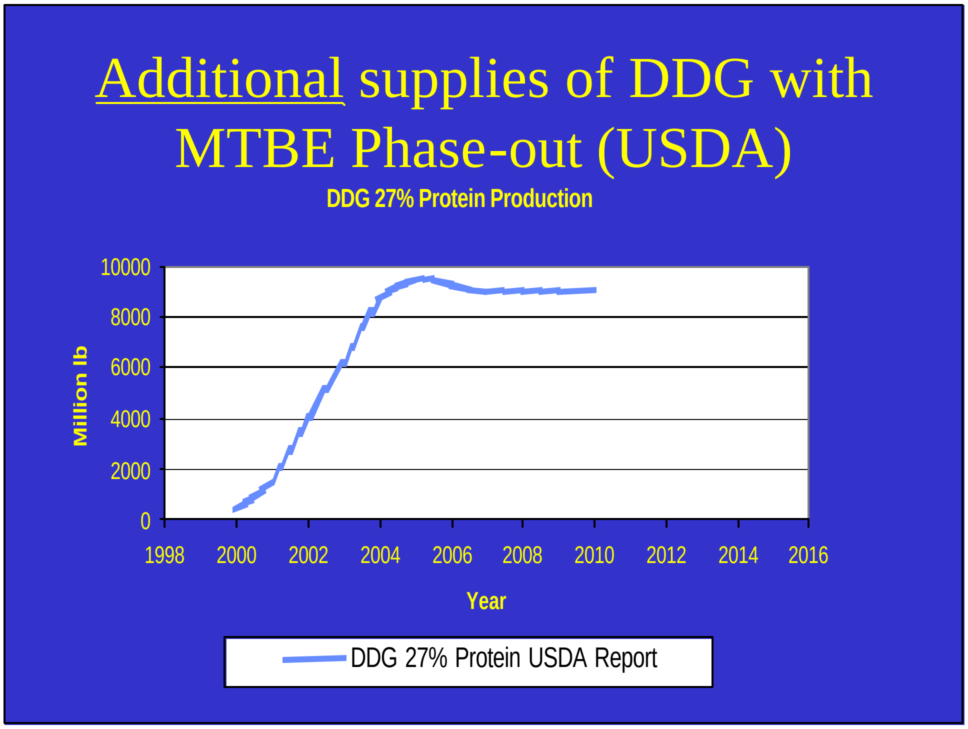
- MTBE – how much future use?
- Other ethers – what will be their role for gasoline blending? What will they cost?
- How will the RFG and oxy-fuel gasoline markets grow in the future?
- Will more states require ethanol blending for gasoline?
- Will there be a Renewable Fuel Standard?

External Issues and Market Competition

- Price of Oil, Blend Stocks, and Gasoline
- U.S transportation fuels supply and demand issue
  - U.S. energy policy and homeland security
- U.S. environmental policy
  - Future transportation fuel composition standards
  - Global climate change, GHG emissions, carbon taxes
- Price and Availability of Starch (Grain) Ethanol
  - What will corn prices be at high levels of ethanol and chemical production?
  - What will be the markets for starch ethanol co-products?

Future Corn Ethanol Market Issues to be Researched

- Rapid rise in corn ethanol production & starch based chemicals -- How much upward pressure will it put on corn prices?
- If corn prices reach $2.70 – 3.50/bushel, older dry mills may lose profitability
- Large ramp-up in DDG production may saturate feed markets, lower prices


Additional supplies of DDG with MTBE Phase-out (USDA)
DDG 27% Protein Production
10000
8000
6000
4000
2000
0
Million lb
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year
DDG 27% Protein USDA Report

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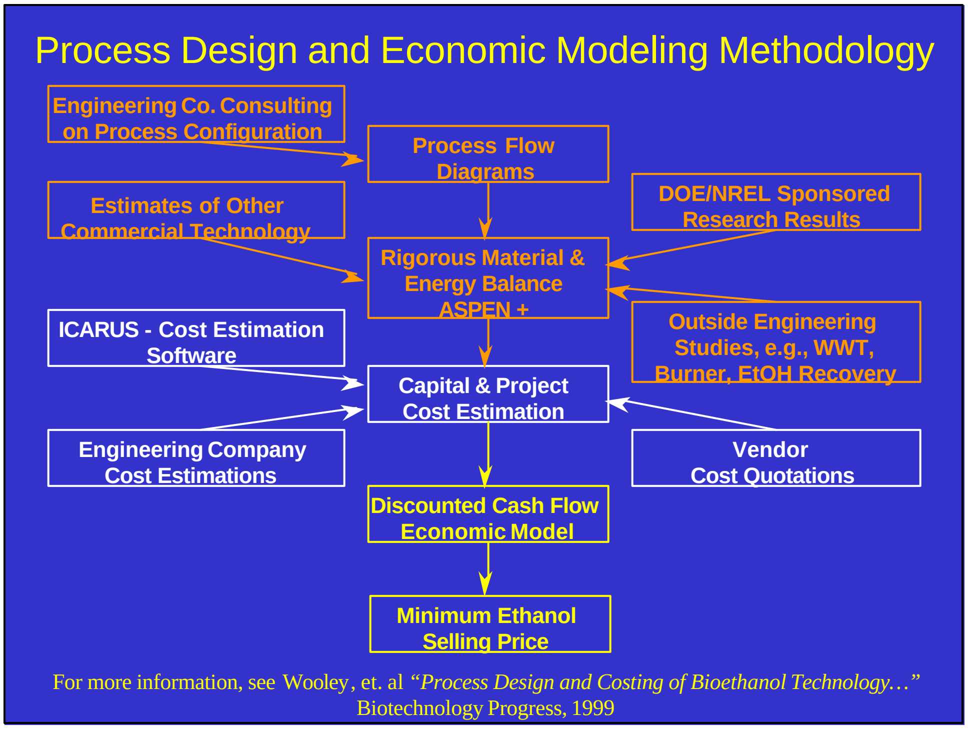
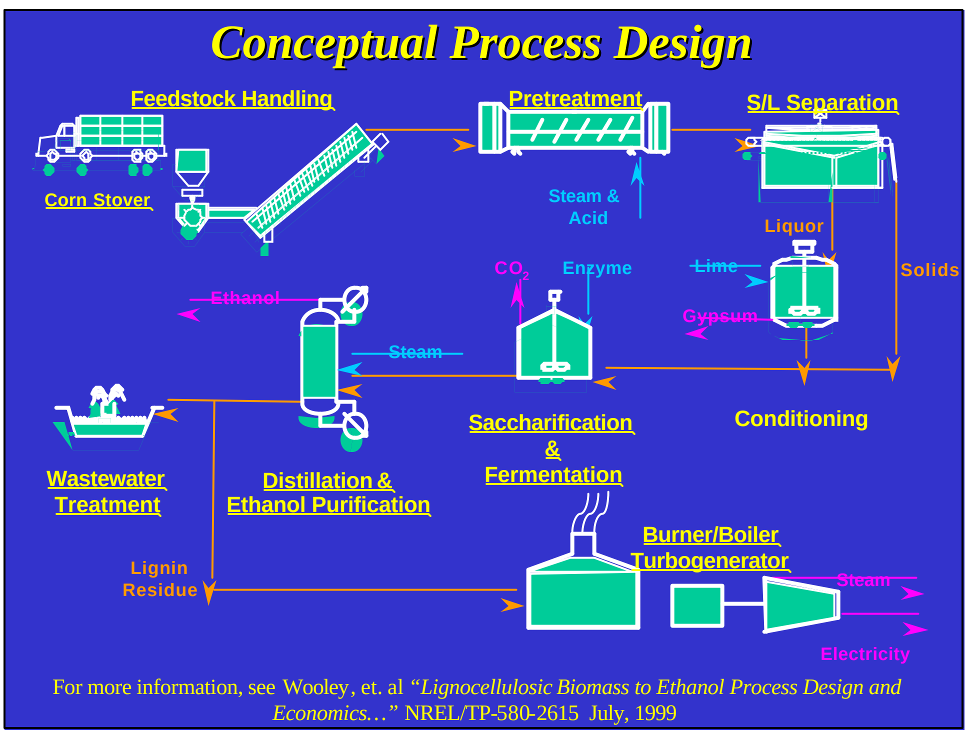
Technical and Economic Feasibility Assessment

Andy Aden

Technical and Economic Feasibility

- Market target price established: $1.10/gallon
- Understand technical feasibility and economic competitive advantage
  - Develop/refine integrated conceptual process models
- Apply models to understand key sensitivities and identify critical success factors
  - Potential for cost reduction beyond process case
  - Impacts of not achieving research targets


Process Design and Economic Modeling Methodology
Engineering Co. Consulting on Process Configuration
Process Flow Diagrams
Estimates of Other Commercial Technology
DOE/NREL Sponsored Research Results
Rigorous Material & Energy Balance ASPEN +
Outside Engineering Studies, e.g., WWT, Burner, EtOH Recovery
ICARUS - Cost Estimation Software
Capital & Project Cost Estimation
Engineering Company Cost Estimations
Vendor Cost Quotations
Discounted Cash Flow Economic Model
Minimum Ethanol Selling Price
For more information, see Wooley, et. al *"Process Design and Costing of Bioethanol Technology…"* Biotechnology Progress, 1999


Conceptual Process Design
Feedstock Handling
Corn Stover
Pretreatment
Steam & Acid
S/L Separation
Liquor
Solids
Lime
Gypsum
Conditioning
CO_2
Enzyme
Ethanol
Steam
Saccharification & Fermentation
Wastewater Treatment
Distillation & Ethanol Purification
Lignin Residue
Burner/Boiler Turbogenerator
Steam
Electricity
For more information, see Wooley, et. al *"Lignocellulosic Biomass to Ethanol Process Design and Economics…"* NREL/TP-580-2615 July, 1999

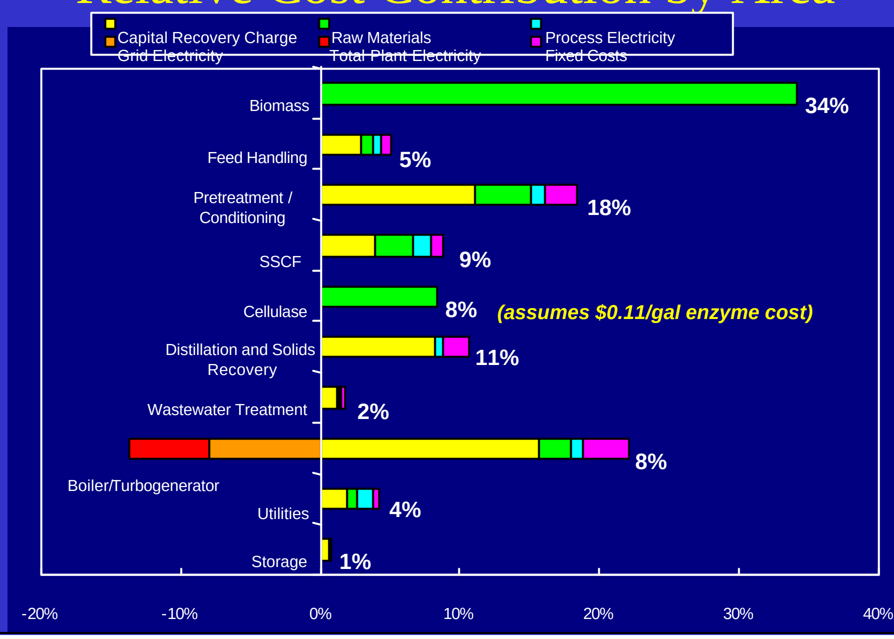
Estimated Process Economics

Plant Size: 2000 MT Dry Corn Stover/Day (Greenfield Site)
Corn Stover Cost: $35/dry ton

Economic Parameter (Units, $1999)	Value
Min. Ethanol Selling Price ($/gal)	$1.30
Ethanol Production (MM gal/yr)	60
Ethanol Yield (gal/dry ton stover)	77.5
Total Project Investment ($ MM)	$200
TPI per Annual Gallon ($/gal)	$3.34
Net Operating Costs ($/gal)	$0.73

* Assuming 100% equity financing and 10% Internal Rate of Return (IRR)

Relative Cost Contribution by Area



Feedstock – Corn Stover

Model Parameter*	Value
Feedstock Cost	$35/dry ton
Cellulose Fraction	37.1%
Xylan Fraction	19.9%
Arabinan Fraction	2.5%
Mannan Fraction	1.3%
Galactan Fraction	1.7%
Lignin Fraction	18.2%

*** Composition based on NREL data**

Feedstock – Corn Stover

Data Sources:

- Feedstock Cost:
  - Walsh, et.al. (ORNL)
  - Demonstrated by B/MAP in Harlan, IA
- Feedstock Composition:
  - Averaged stover data (NREL)
  - Research underway to improve analysis methods and understand compositional variance

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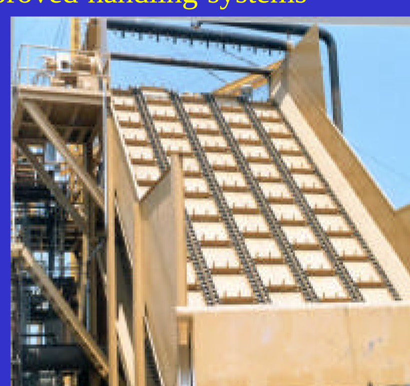
*** Composition based on NREL data**

Feedstock – Corn Stover

$0.13/gal change for every $10/BDT change

Feedstock Handling

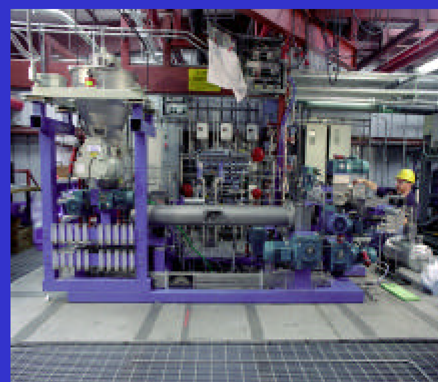
- Brings biomass into facility
- Prepares biomass for pretreatment
- Subcontract work to develop improved handling systems



Pretreatment

- Converts hemicellulose to fermentable sugars
- Makes cellulose susceptible to enzymatic hydrolysis

Conditions:	
Technology	Dilute Acid
Reactor Solids Concentration	30 %
Residence Time	2 min
Acid Concentration	1.1 %
Temperature	190 °C
Reactor Metallurgy	Incoloy 825-clad



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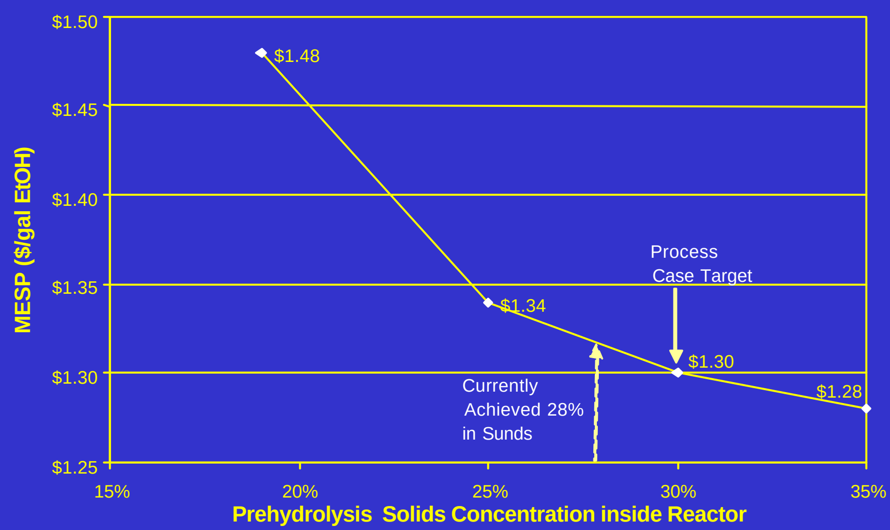
Residence Time	2 min
Acid Concentration	1.1 %
Temperature	190 °C
Reactor Metallurgy	Incoloy 825-clad

Parameter Source:

- Corn stover Sunds hydrolyzer experiments
- Corn stover steam gun experiments
- Prior research on hardwood feedstocks

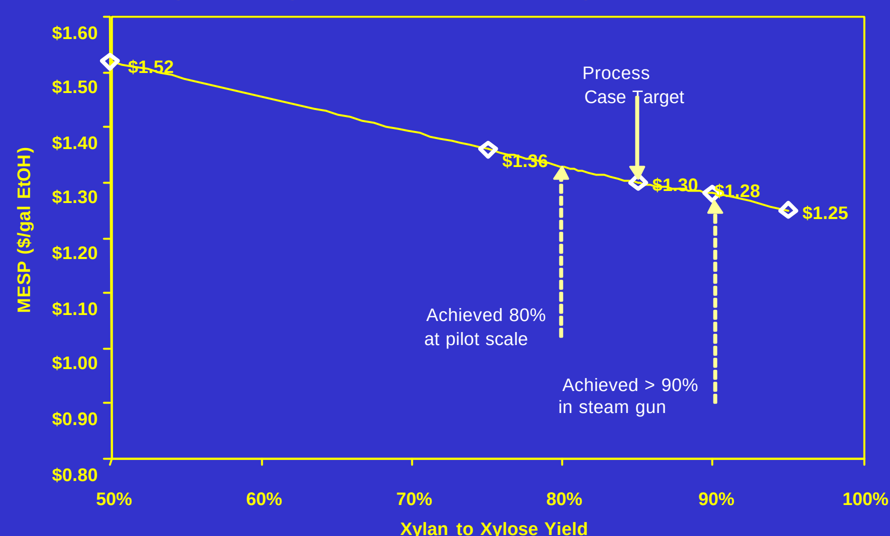
Pretreatment

Reactor Solids Cost Impact:

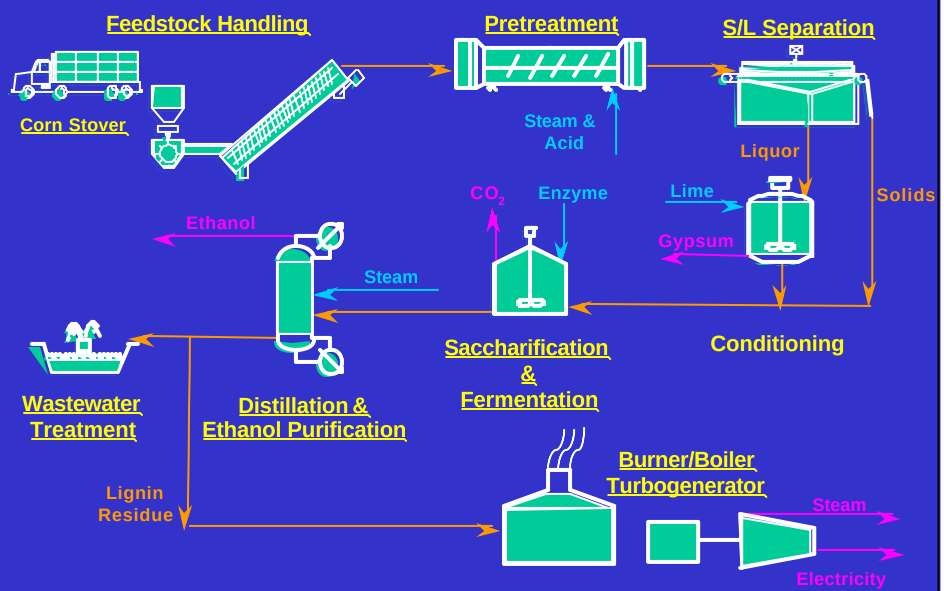


Pretreatment

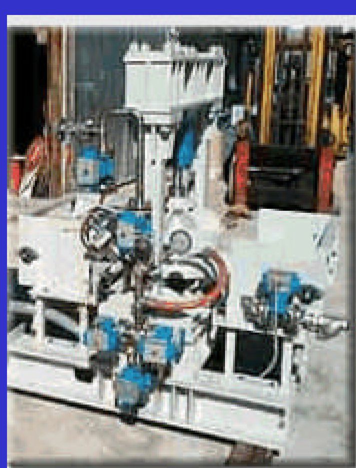
$0.06/gal change for each 10% change in xylose yield



Conceptual Process Design



Solid/Liquid Separation and Conditioning



- Separation of pretreatment solids from liquor
- Enables conditioning of liquor fraction prior to fermentation

Conditions:	
Equipment	Pressure Filter
Separation Temp	135 °C
Separation Pressure	5 atm
Conditioning	Overlime only
Wash / Hydrolysate Ratio	0.58 kg/kg

Solid/Liquid Separation and Conditioning

- Separation of pretreatment solids from liquor
- Enables conditioning of liquor fraction prior to fermentation

Rationale:

- – Lower acetylation of corn stover hemicellulose means IX may not be needed to reduce acetic acid levels
- – Cost impact $0.07/gal

Parameter Source:

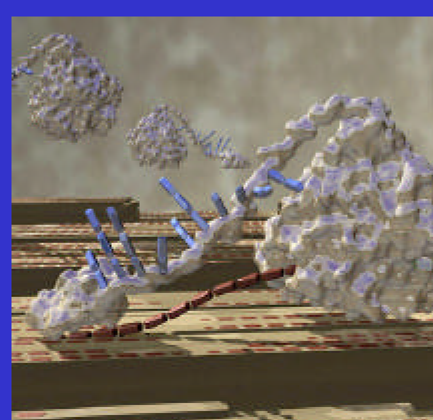
- – Critical equipment subcontract
- – Overliming subcontract

Conditions:	
Equipment	Pressure Filter
Separation Temp	135 °C
Separation Pressure	5 atm
Conditioning	Overlime only
Wash / Hydrolysate Ratio	0.58 kg/kg

Saccharification & Fermentation

- Enzymatic hydrolysis of cellulose to glucose
- Microbial conversion of sugars to ethanol

Saccharification:	
Enzyme Source	purchased
Enzyme Cost	$0.11/gal EtOH
SHF vs. SSF	Hybrid
Temperature	65 °C
Residence Time	1.5 days
Cellulose to Glucose Yield	90%



Saccharification & Fermentation

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Enzyme Cost	\$0.11/gal EtOH
SHF vs. SSF	Hybrid
Temperature	65 °C
Residence Time	1.5 days
Cellulose to Glucose Yield	90%

Parameter Source:

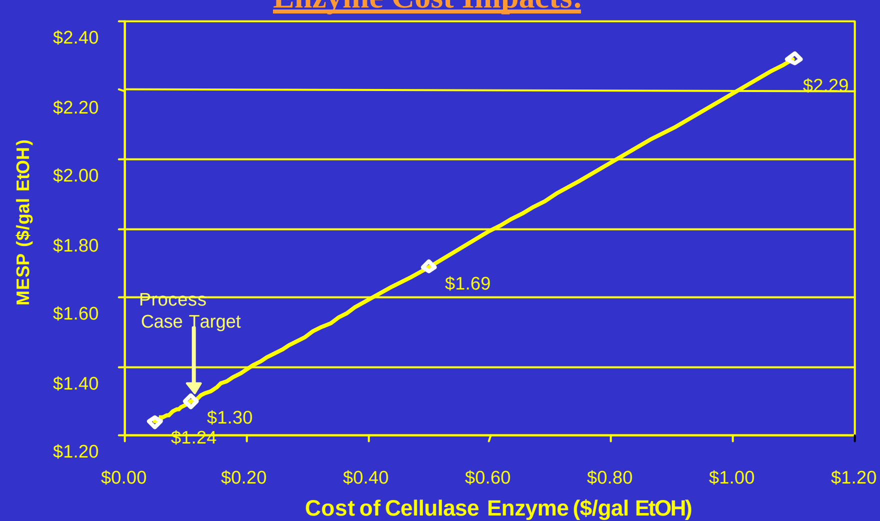
- Enzyme Cost is 10x-reduction from Glassner-Hettenhaus parameters

  "Enzyme Hydrolysis of Cellulose"
  Glassner, D.; Hettenhaus, J.
  1997

- Enzyme subcontracts w/ Genencor & Novozymes
- Hybrid design advantageous for more thermostable enzyme system

Saccharification & Fermentation

Enzyme Cost Impacts:



Saccharification & Fermentation

- Enzymatic hydrolysis of cellulose to glucose
- Microbial conversion of sugars to ethanol

Fermentation:	
Residence Time	2 days
Temperature	37 °C
Nutrient Requirement	0.25% CSL 0.33 g/L DAP
Effective Solids Conc.	20%

Saccharification & Fermentation

- Enzymatic hydrolysis of cellulose to glucose
- Microbial conversion of sugars to ethanol

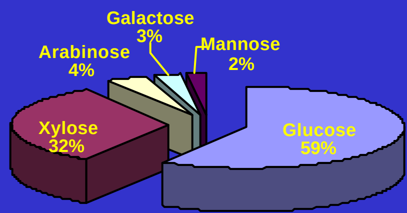
Parameter Source:

- Based on prior conversion of hardwood hydrolyzates using *Z. mobilis*
  - Nutrients
- Strain improvements
  - Arabinose Yeast CRADA
  - Other government sponsored research

Fermentation:	
~~Residence Time~~	~~2 days~~
~~Temperature~~	~~37 °C~~
Nutrient Requirement	0.25% CSL ~~0.33 g/L DAP~~
~~Effective Solids Conc.~~	~~20%~~

Saccharification & Fermentation

- Enzymatic hydrolysis of cellulose to glucose
- Microbial conversion of sugars to ethanol



Relative Fractions of Sugars Within Corn Stover

Yields:	
Glucose to Ethanol Yield	92%
Xylose to Ethanol Yield	85%
Arabinose to Ethanol Yield	85%
Contamination Loss	5%

Saccharification & Fermentation

- Enzymatic hydrolysis of cellulose to glucose
- Microbial conversion of sugars to ethanol

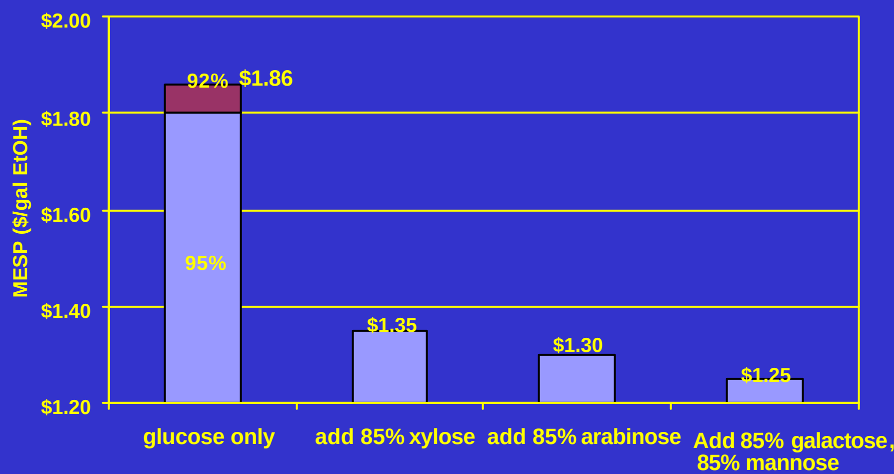
Parameter Source:

- Initial work based on glucose and xylose co-fermenting *Z. mobilis*
- Improved strains constructed with broader pentose and hexose substrate ranges
  - rDNA yeast, bacteria

Yields:	
Glucose to Ethanol Yield	92%
Xylose to Ethanol Yield	85%
Arabinose to Ethanol Yield	85%
Contamination Loss	5%

Saccharification & Fermentation

Fermentation Yield Cost Impacts:



Distillation & Ethanol Purification

- Separation of ethanol and CO_2 from "beer"
- Ethanol concentration in beer calculated at 5% w/w
- Primary Unit Operations
  - Distillation
  - Pressure-swing adsorption (mol sieve)
  - Solid/liquid separation
  - Evaporation
- Operations well-known
- Process uncertainties
  - Solids behavior

Wastewater Treatment

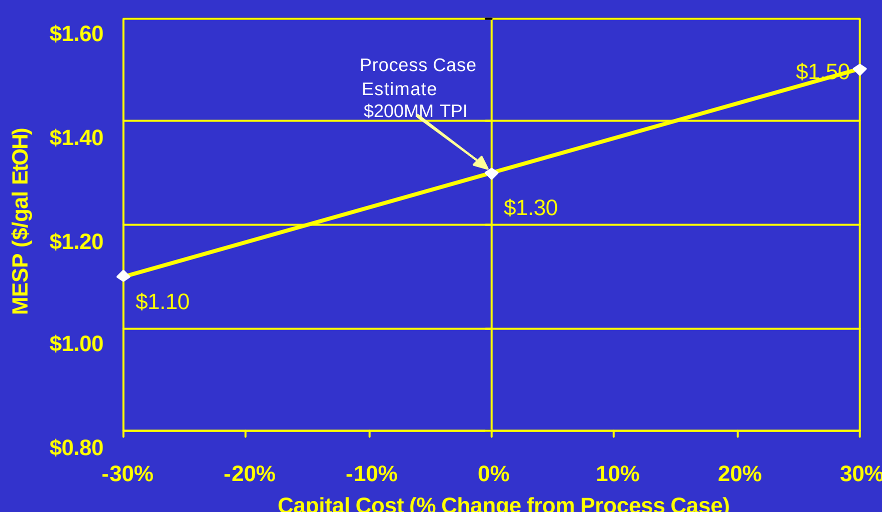
- Anaerobic and aerobic treatment
- Reduce Biochemical Oxygen Demand (BOD)
- Recycle water

Burner/Boiler/Turbogenerator

- Biomass boiler generates steam from lignin residue & evaporator syrup
- Excess electricity from generator sold to power grid ($0.04/kWh credit)
- High capital cost area (35% of total installed cost)

Capital Cost Impact

$0.07/gal change for each 10% change in Capital Cost



Assessment Findings

- Current process performance targets translate to $1.30/gal MESP for 2000 dry (metric) tonnes/day grassroots facility
  - Total Project Investment (TPI) estimated at $200 MM
  - Annual ethanol production is 60 MM gallon per year.
- Additional $0.20/gal savings required to meet market target
  - Co-locate to reduce capital costs
  - Decrease operating costs / increase revenue
- Estimated TPI/annual gallon is more than $3.00
  - Roughly 3x higher than corn dry mills
- Difficult to compete for financing, even if operating costs are competitive

Financial Assessment – Part 2 How to get to $1.10/gallon

Objective: identify compelling scenarios

- Extend sensitivity analysis
  - Explore deployment scenarios: what options for cost reduction?
    - Operating costs: Feedstock cost, raw materials
    - Capital costs
    - Financing (equity financing)
    - Co-products

Deployment Scenarios

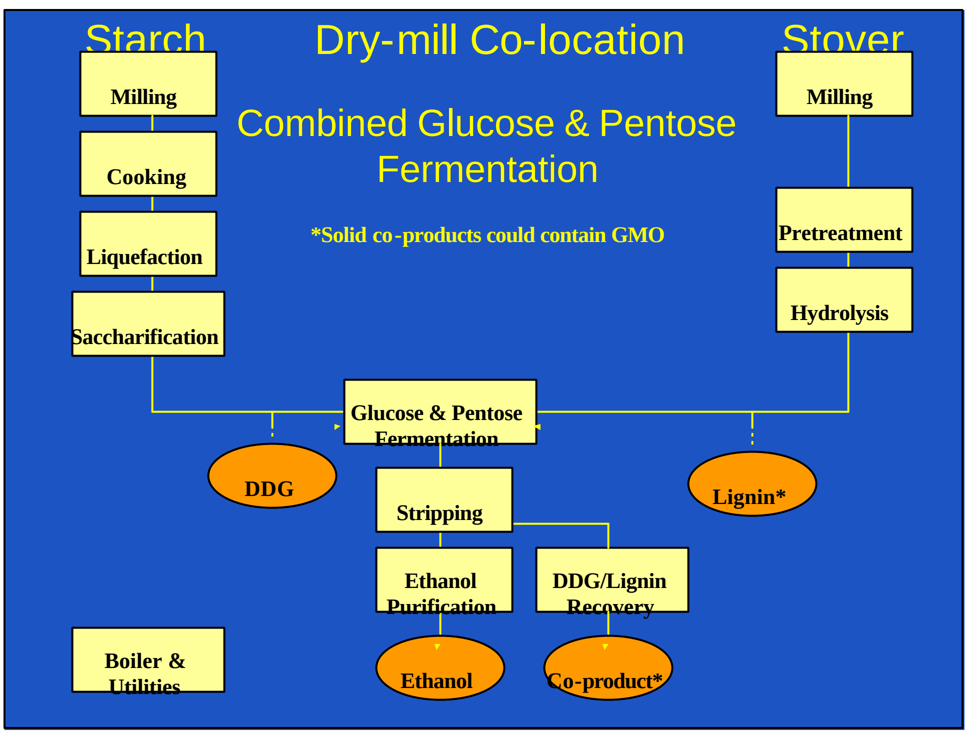
- Reduce feedstock cost
  - More efficient feedstock collection methods (anticipated through ORNL/USDA efforts)
- Minimize enzyme cost
  - Genencor and Novozymes
- Increase revenues
  - Exploit co-products
    - Being explored by DOE OIT, USDA ARS, etc.
- Reduce plant capital cost
  - Used equipment/brownfield site
  - Co-location
  - Financing

Co-location Scenario Development

Options	Operating Costs	Ferm. Cap. Cost	Distill. Cap. Cost	Utility & WWT Cap. Cost
Corn starch ethanol				
Dry mill	🗳	?	🗳	🗳
Wet mill	🗳	?	🗳	🗳
Power plant				
Coal	?			🗳
Biomass	?			🗳

Current Biofuels Co-location Studies

- Wet mill fiber conversion demonstration
  - Williams Bioenergy and Purdue
  - Pilot scale
- Dry mill study
  - USDA Phase II collaboration with NREL
- Coal-fired power plant studies
  - Easterly Consulting
  - BBI International
- Biomass power plant studies
  - Pacific Institute
  - CEC/Collins Pine



Dry-mill Co-location Preliminary Process Economics

Economic Parameter (Units, $1999)	Process Case	Co-location:* Stover	Corn
Minimum Ethanol Selling Price ($/gal)	$1.30	$1.23	
Ethanol Production (MM gal/yr)	60	30	30
Ethanol Yield (gal/dry ton stover)	77.5	77.5	
(gal/bushel corn)			2.85
Total Project Investment ($ MM)	$200	$109	$70
TPI per Annual Gallon ($/gal)	$3.34	$1.83	$1.16
Net Operating Costs ($/gal)	$0.73	$0.72**	

* Greenfield combined corn and stover plant; dry-miller pays for dry mill areas

** Net Annual Operating Costs for dry mill $0.89 - $1.09/gal according to 1998 USDA survey

Coal-fired Power Plant Co-location Preliminary Process Economics

Economic Parameter (Units, $1999)	Process Case	Coal-fired Power Plant Co-location*
Minimum Ethanol Selling Price ($/gal)	$1.30	$1.18
Ethanol Production (MM gal/yr)	60	60
Ethanol Yield (gal/dry ton stover)	77.5	77.5
Total Project Investment ($ MM)	$200	$130
TPI per Annual Gallon ($/gal)	$3.34	$2.17
Net Operating Costs ($/gal)	$0.73	$0.82

* Existing Power Plant; lignin residue sold at $1.25/MMBtu
Steam purchased at $1.50 - $2.50/MMBtu; electricity purchased at $0.04/kWh

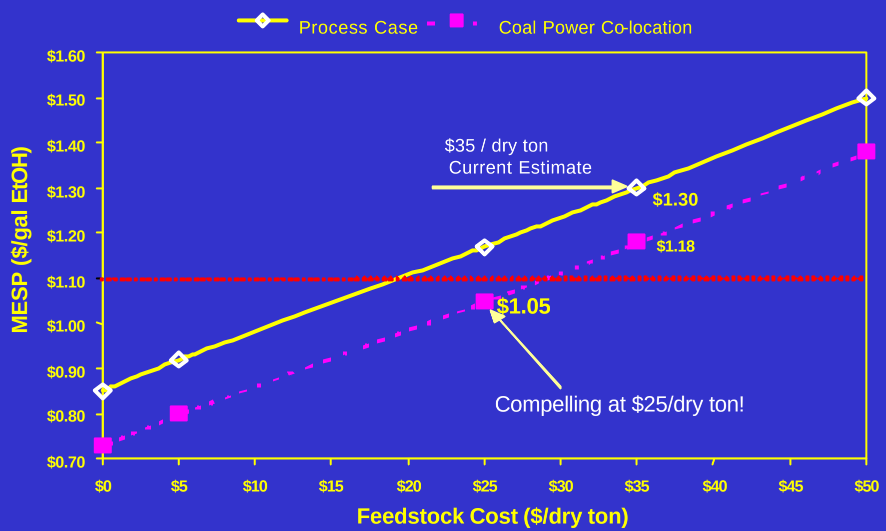
Comparative Process Economics

Economic Parameter (Units, $1999)	Process Case	Dry-mill Co-location	Coal-fired Power Plant Co-location
MESP ($/gal)	$1.30	$1.23	$1.18
EtOH Production (MM gal/yr)	60	30 / 30	60
EtOH Yield (gal/dry ton stover)	77.5	77.5	77.5
(gal/bushel corn)		2.85	
TPI ($ MM)	$200	$109 / $70	$130
TPI per Annual Gallon ($/gal)	$3.34	$1.83 / $1.16	$2.17
Net Operating Costs ($/gal)	$0.73	$0.72	$0.82

Combined Scenarios

- Co-location with
  - *Lower feedstock cost*
    - Coal power plant and $25/dry ton feedstock
  - *Improved financing*
    - Dry-mill and 25% equity; 5% interest, 15 yr term
  - *Higher-value co-products*
    - Coal power plant and $70/dry ton lignin residue
- Lower feedstock cost with improved financing
  - $25/dry ton feedstock and 25% equity; 7% interest, 15 yr term

Coal-fired Power Plant Co-location and $25/dry ton Stover



Combined Scenario Economics

Economic Parameter (Units, $1999)	**Process Case**	**Coal Power $25/dt Stover**	**Coal Power $70/dt Lignin**	**Dry-mill 5% int, 15 yr 25% equity**	**$25/dry ton Stover 7% int, 15 yr 25% equity**
MESP *($/gal)*	$1.30	$1.05	$1.10	$1.09	$1.07
EtOH Prod. *(MM gal/yr)*	60	60	60	30 / 30	60
Yield *(gal/dt stvr)*	77.5	77.5	77.5	77.5	77.5
TPI *($ MM)*	$200	$1.30	$130	$109 / $70	$200
TPI / ann gal *($/gal)*	$3.34	$2.17	$2.17	$1.83 / $1.16	$3.34

Assessment - Part 2: Conclusions

- **Compelling scenarios can be achieved!!**
- Many scenarios yet to be examined in detail
- No single business scenario other than lower feedstock cost can reach the target MESP
  - Target MESP reached at $20/BDT
- Capital costs should be targeted for reduction
  - NREL depending on others to help with net operating costs (feedstock, enzyme, co-products)

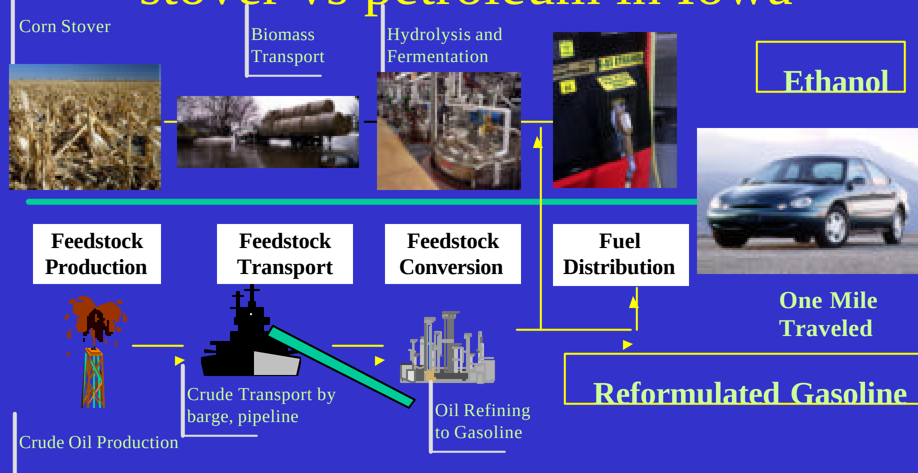
Proposed Stage 3 Activities

- Work with industry to refine/develop conceptual process
- Continue detailed examination of business case scenarios
- Extend model capabilities
  - Improve kinetic models

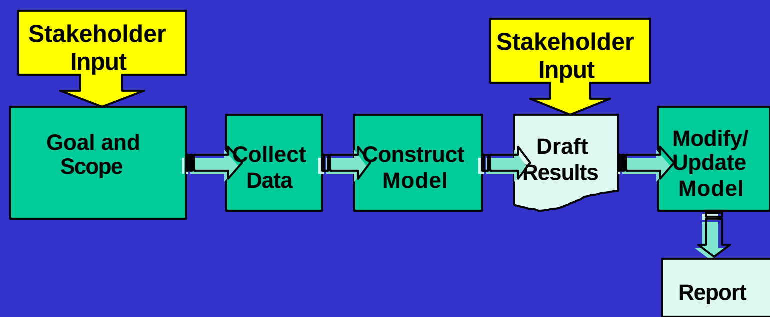
Life cycle analysis:
Keeping an eye on the big picture

- A tool for looking at fuel choices from "cradle to grave"
- A tool for identifying showstoppers beyond our technology scope
- LCA is the only tool for understanding how well our projects align with the strategic goals and mission of the Biofuels Program

The system—corn stover vs petroleum in Iowa



Life cycle analysis—a tool for dialogue



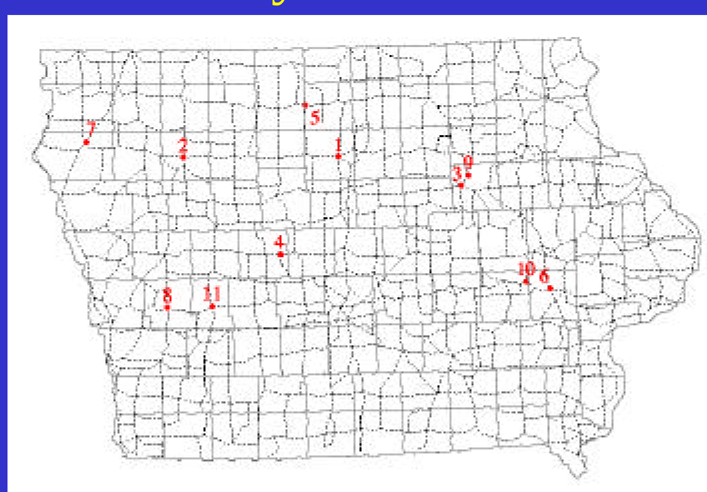
In our corn stover to ethanol study we involved:

- Environmental groups
- Farmers
- Automakers
- Ethanol producers
- USDA
- EPA
- DOE

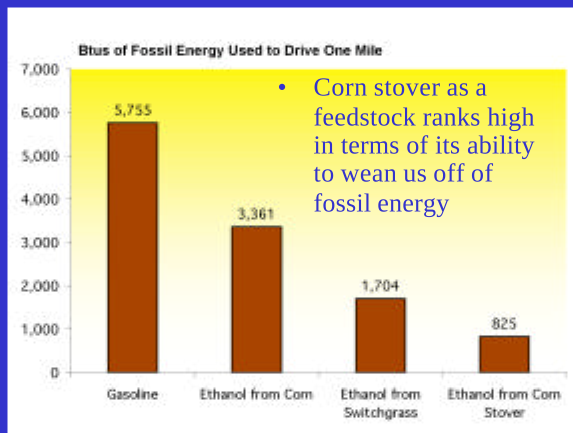
Stakeholder input: Sustainability is the watchword

- Homeland security
- Fossil energy avoidance
- Land use and biodiversity
- Greenhouse gas
- Soil sustainability
- Urban air emissions
- Air and water toxics
- Solid waste
- Eutrophication
- Acidification
- Community—rural jobs, local economy

The System—Iowa



Avoiding fossil fuel use: bioethanol from corn stover



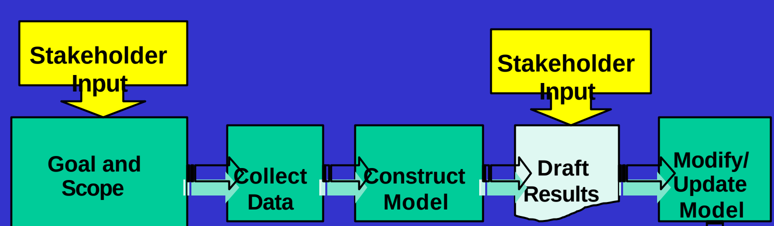
LCA—what have we learned in stage 2?

- The life cycle framework is a great mechanism for finding common ground among stakeholders and experts
- For the first time, a life cycle assessment of greenhouse gases has incorporated soil effects
- Corn stover-derived ethanol makes personal mobility more sustainable
  - Three fold reduction in petroleum consumption
  - Seven fold reduction in fossil
  - Climate change benefits (wait til this afternoon!)
  - Soil health (wait till this afternoon)

LCA—what do we need to do in stage 3?

- Take the show on the road
  - Get feedback on our work and its implications for sustainable use of corn stover
- Vastly improve our understanding of soil health effects

LCA—the ultimate goal



The ultimate goal is to be able to make sustainable choices and how stover-derived ethanol fits.